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DEVELOPMENT AND TESTING OF A DIGITAL LEAN TOOL TO SHARPEN MOTION AND TRANSPORTATION WASTE RECOGNITION

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ABSTRACT

There is a need to create ways to communicate opportunities for motion and transportation waste reduction and productivity enhancement that align with the visual management characteristics of those practicing within the construction industry. In this study, researchers aimed to evaluate the effectiveness of an interactive online simulation game that generates spaghetti diagrams as a tool for improving conceptual understanding of motion and transportation waste reduction, that could potentially be used by lean educators in the construction industry. The tool was developed using Unity™ and tested against a control group. To ensure the concept was relatable to participants across different roles, the commonly experienced activity of making spaghetti was chosen as the simulation scenario. Participant feedback from preliminary testing of the online simulation game indicated that the activity was enjoyable and appeared to heighten participant awareness of object placement. Metrics generated by the simulation—as well as post-play discussion—appeared to help participants perceive how elimination of motion and transportation waste can potentially improve their performance. The intent of the simulation is to spur post-simulation discussion with participants about identifying and reducing waste in their own varied processes such as job site operations and procurement.

KEYWORDS

Motion waste, transportation waste, lean simulation, lean construction, online game, serious games, spaghetti diagram, productivity awareness

INTRODUCTION

Simulation games can be used in the classroom to promote learning, facilitate classroom instruction, and boost comprehension among students (Bhatnagar et al., 2022; Hamzeh et al., 2017). Furthermore, students expect university education to be entertaining and simulation games can impart learning in an enjoyable way (Kapp, 2012; Prensky, 2007).

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A review of relevant literature suggests that a spaghetti diagram is a potentially impactful tool that can help reduce unnecessary movements. Kanaganayagam (2015) describes a spaghetti diagram as a method of visualizing the path of movement of an actor or object using a line. By identifying motion and transportation waste, spaghetti diagrams help organizations reduce superfluous labor and implement changes to organizational structure or workstation layouts (Senderska et al., 2017). Spaghetti diagrams are powerful tools to identify and reduce unnecessary motions. However, a major drawback is that traditional spaghetti diagrams are static and time-consuming to create, limiting their usefulness for dynamic environments such as construction sites. While vision-based approaches allow for real-time monitoring, they do not currently offer the ability to quickly generate spaghetti diagrams to visualize motion waste. This presents a significant opportunity for the construction industry to improve their processes by leveraging the potential of rapidly generated spaghetti diagrams. This research proposes that an online game generating spaghetti diagrams can potentially enhance the performance of the construction industry by presenting visual opportunities for reducing waste and improving productivity.

EXPERIENTIAL LEARNING AND SERIOUS GAMES

Experiential Learning, often referred to as involved, evidential, or situational learning, is a participatory, interactive, and practical style of learning (Hawtrey, 2007). It permits environmental interaction and exposure to varied and unpredictable processes (Gentry, 1990).

Experiential learning, in its more advanced forms, provides possibilities for "data learning" by requiring students to actively participate in the learning process and to engage in expression of their ideas, utilization of inductive reasoning, or collaboration within groups. In fact, when a participant transitions from the role of a passive listener to an active respondent, this process is known as experiential learning (Hawtrey, 2007).

This research is focused on game-based learning which is aligned with experiential learning. The serious game movement is a response to the need to combine play and meaningful content with advanced capabilities (Spires, 2008). Games in this category incorporate social themes or problems into the gameplay, giving players a fresh viewpoint through active participation (Johnson et al., 2012).

Several studies, including Cassidy (2003), Sacks et al. (2007), and Tommelein et al. (1999), have demonstrated that computer simulations can be more effective than traditional methods of instruction. However, to ensure effectiveness, it is essential to develop a user-friendly design with clear instructions and graphics which illustrate that which is to learned (Gadre et al., 2011; Kuriger et al., 2010). Additionally, feedback is critical for knowledge and skill improvement. Without accurate feedback, learners cannot draw reliable conclusions about that which have learned (Gentry, 1990).

SIMULATIONS AND GAMES IN LEAN EDUCATION

Lean philosophy has given rise to principles and a set of tools to help identify and eliminate waste embedded within processes through the practice of continuous improvement. Elimination of waste, addition of value, continuous improvement, and a culture of respect are the four cornerstones of Lean philosophy (Rybkowski et al., 2018). Although they were arguably built upon productivity theories from Frederick Taylor, Frank and Lillian Gilbreth, and W. Edwards Deming, among others, lean concepts are often summarized as part of The Toyota Production System (TPS). Koskela (2000) is credited with being among the first to apply Lean principles to the construction industry.

A central notion in Lean is waste reduction, which Toyota defines as "anything other than the absolute minimum quantity of materials, equipment, and labor required to add value to the product" (Alarcon, 1997, p. 1). Many authors define lean as a technique for reducing waste.

However, others have argued the actual purpose of reducing waste is to free up resources to enable maximizing value (Sundar et al., 2014). While others have since argued there are additional wastes, Taiichi Ohno originally listed seven: overproduction, time on hand, transportation, processing itself (e.g. overprocessing), stock on hand, movement (i.e. motion), and defective goods. Ohno contended that getting rid of these wastes would lower production costs and boost profits (Ohno, 1988).

Building operations can be optimized using Lean waste elimination principles and analysis of value-adding and non-value-adding activities. Simulation games can serve as a valuable tool to teach these principles and tap into Lean's potential in the field of construction and its business operations (Bhatnagar & Devkar, 2021).

Although Lean concepts such as flow, value, waste reduction, and value maximization are promising and have the potential to improve construction processes, a literature review suggests that the complexity of Lean philosophy and a lack of knowledge about Lean are considered potential barriers to the adoption of its principles in the construction industry (Demirkesen et al., 2019).

Simulation games provide a unique opportunity for hands-on learning, effectively bridging the gap between theoretical knowledge and practical applications in Lean philosophy. In fact, Lean pioneers Greg Howell and Glenn Ballard began experimenting with Lean Construction simulations as early as the 1980s. Simulation games have traditionally been utilized to teach outsiders about Lean building practices and processes, and have proven to be a valuable tool for promoting understanding and engagement with Lean concepts (Tsao & Howell, 2015).

Simulation games provide a dynamic and error-free learning environment that allows individuals to gain a deeper understanding of Lean principles through hands-on experience. By providing a realistic simulation of real-life scenarios, simulation games promote learning through physical activities and enable individuals to translate their knowledge into practical skills (Galloway, 2004). Visual representations of processes and metrics play a crucial role in helping players understand the consequences of their decisions and strategies in these games. By presenting data in a visually engaging manner, players can easily grasp the impact of their actions and make informed decisions to improve their performance. This enhances the learning experience and allows for a deeper understanding of Lean principles (Shannon et al., 2010).

SPAGHETTI DIAGRAM

A spaghetti diagram is a technique used to visualize the movement of an object in a system (Kanaganayagam et al., 2015). Due to the likeness of the results to cooked spaghetti, the tool was given the name spaghetti diagram.

Within the Lean manufacturing paradigm, spaghetti diagrams are commonly utilized as improvement tools (Gladysz et al., 2017). A spaghetti diagram can be used to identify movement durations, multiple movements and overlapping motions. Transportation and motion wastes are revealed using a spaghetti diagram, enabling the reduction of unnecessary labor, and modifications to organizational structure or workstation arrangements (Senderska et al., 2017).

These diagrams are a tried-and-true method for finding layouts that work better (Bicheno & Holweg, 2008). It is relatively simple to identify opportunities to decrease movement waste when the transportation routes are made clear. This visual transparency makes it possible to analyze each movement, revealing areas where motions can be improved. Staff members or workers are observed performing their duties, and the route they take is graphically traced onto a two-dimensional floor plan (Lean Consulting Group, 2016).

The spaghetti diagram is a valuable tool for enhancing our understanding of work processes, particularly when it comes to the distances travelled by production workers. Inefficient material staging arrangements resulting in waste from unnecessary and empty transportation can often be addressed through the rapid visualization of movement, even with modest technologies.

While traditionally hand-drawn, the development of software products is now facilitating the process of creating spaghetti diagrams. By capturing a worker's motions throughout the work cycle being studied and tracing them onto a two-dimensional plan, a spaghetti diagram can be created with greater accuracy and efficiency. Using software such as visTABLE® is a logical and practical approach to creating spaghetti diagrams and is certainly helpful during design of projects such as healthcare facilities where movements of healthcare workers should be minimized (Weber, 2022). While visTABLE® software is a logical tool for creating spaghetti diagrams, it currently cannot generate diagrams in real-time. To address this limitation, this research explores the effectiveness of a dynamic post-action spaghetti diagram incorporated into an online game in improving worker performance. One potential issue with using spaghetti diagrams is the possibility of altered behavior from workers who are aware of being observed. To address this concern, a dynamic spaghetti diagram can be constructed continuously and without the knowledge of workers being analyzed, providing a potential remedy to this drawback (Gladysz et al., 2017).

AWARENESS ENHANCEMENT

An expanding number of research studies support the use of visualization as a tool for problem solving and awareness enhancement. Visualization improves information comprehension by encouraging immediate linkage and perceived associations. In order to achieve this, information must be presented in a way that makes it easier for a user to process it and reduce the amount of mental adjustments needed (Livnat et al., 2005).

For example, in studies focused on raising energy awareness, visibility of energy consumption appears to play a crucial role. According to a survey by Hassan et al. (2009), increased visibility of energy use motivated users to reduce energy consumption. Additionally, a study conducted by Jachimowicz et al. (2018) showed that sharing energy use data with users resulted in energy savings between 0.81% and 2.55%. Sharing this kind of data with users appears to increase their awareness and alter the direction of their actions. When unbiased measurements make them more aware of their actions, users appear to better grasp what they are doing that jeopardizes a goal and what they need to change to reach that goal.

The use of visual management (VM) technologies has grown, and successful implementation instances have been recorded (Brandalise et al., 2022; Tezel, 2011). VM is a component of the Toyota Production System (TPS) and is frequently linked to lean construction (Koskela, 1992). Applications for visual management are designed to make information more easily accessible so that process participants can take appropriate action at the right time (Koskela, 2001; Liker et al., 1995). For example, the increasing ubiquity of BIM facilitates VM before actual construction. By analysing the frequency and intensity of a worker's actions, non-value-adding activities (waste) are easier to identify. Project managers, superintendents, and foremen can benefit from developing situational awareness, but it is arguably equally important for workers to develop this skill by offering them a before-and-after "snapshot" of their own movements (Ghimire et al., 2017; Reinbold et al., 2019).

RESEARCH GAP

The objective of this study was to examine whether exposing individuals to digitally generated spaghetti diagrams can enhance their personal awareness of value-adding and non-value-adding activities, and lead to a reduction in their own movements. However, the creation of accurate spaghetti diagrams is a skill that requires time and practice. Furthermore, existing diagrams are often static and fail to capture transportation dynamics (Gladysz et al., 2017). In response to this need, a real-time diagram-generating algorithm was incorporated into an online game developed for this research.

The following were the procedures and objectives of this research study:

- Develop a real-time spaghetti diagram into an online game which can incorporate distance travelled; and
- Collect feedback to determine whether or not the spaghetti diagram generated by the online game helps participants identify opportunities for enhanced productivity.

The research question was as follows: Will students and construction professionals enhance their performance (reduce motion and transportation) when exposed to visual spaghetti diagrams incorporated into an online game?

RESEARCH METHOD

The cross-platform game engine Unity® 3D by Unity Technologies was used in this research to develop a game to determine if a spaghetti diagram could heighten player awareness of opportunities to improve their productivity. Because AEC stakeholders perform a wide range of activities defined by their specific roles, the game was designed to engage participants in a universal activity that is widely relatable to actors across multiple fields and cultures—e.g. the act of making spaghetti (Arefazar & Rybkowski, 2022). The game was inspired by the authors' anecdotal observation that construction workers responded well to a video entitled "Toast Kaizen" (GBMP 2009); these workers argued the video was effective in helping them understand waste identification and elimination on-site because toast-making is a shared experience. The intent is that this simulation may offer a first exposure to participants to waste recognition with the expectation that the graphics could then be replaced with materials and activities related to a stakeholder's specific role, such as supply-chain management, material delivery and laydown areas, equipment placement, structural erection, bricklaying, roofing, etc.

The game was designed in such a way that it could be played using a laptop. The game was designed in 3D view and the view that appears in the game is the plan view. To stage the making of spaghetti, the game depicts a kitchen layout that includes kitchen appliances, utensils, and ingredients needed to make a full plate of spaghetti with meatballs. An avatar cook starts walking when the player clicks on a desired destination. When the cook is close to an object, the object will automatically light up, which signals that the cook can grab that object.

This game has a notable feature of tracking and recording the total distance the player's cook has walked. This information is displayed on the right side of the kitchen's layout after each scenario is completed. The game's objective is to deliver a cooked dish (spaghetti with meatballs) with the least possible distance traveled, and the order of activities is not crucial. Two versions of the simulation were available to players: the control version (Figure 1; orange background) did not provide access to a spaghetti diagram of the cook's movements, while the experimental version (Figure 2; green background) displayed a complete history of the cook's movements via a spaghetti diagram at the end of play. Both versions show players the kitchen, utensils, player's name, level played, travel distance, and elapsed time.

DATA COLLECTION

The research was approved by the Institutional Review Board by Texas A&M University and participants were emailed a consent form before play. The control group participants played the game without being shown a spaghetti diagram, while the experimental group was shown a spaghetti diagram of their path after each round. The experimental group participants' movements were tracked, and a spaghetti diagram was generated on the screen. During the first round, the kitchen layout was pre-set by the program and the layout was identical for each participant; however, during a subsequent round, participants were asked to make a decision about potentially modifying the layout of the kitchen by relocating a stove to one of three possible locations (A, B, or C) as shown in Figure 3.

After each round, the experimental group participants were asked to describe how they used the spaghetti diagram, if at all, to identify a strategy to improve their performance.

After completing the game, both groups were requested to provide plus/delta feedback which is a common tool in Lean philosophy to identify what is working well enough to be retained (plus) and what could be improved (delta). Their feedback was used to improve the game and fix potential deficiencies.

The null hypothesis (H0) and alternative hypothesis (H1) of this research were as follows:

- **H0:** There is no significant difference in improved performance between the control group and the experimental group. Being shown a spaghetti diagram of the cook's path did not help the participants improve their performance.
- **H1:** There is a significant difference in improved performance between the control group and the experimental group. Being shown a spaghetti diagram of the cook's path helped the participants improve their performance.

The researchers aimed to investigate the effectiveness of the spaghetti diagram in enhancing the participants' ability to identify opportunities to reduce motion. To achieve this goal, the study included two groups of participants: an experimental group of 30 individuals and a control group of 30 individuals. The researchers collected performance data from each participant in both groups and compared the results. To test the alternative hypothesis, the researchers employed an unpaired t-test as a statistical analysis method.

DATA ANALYSIS

Information related to the online game participants is depicted in Table 1. Students played the online game during in-person sessions. A live facilitator explained the rules and was available for the duration of the session to help participants with any questions they might have.

For the test session with online lean simulation experts called APLSO (Administering and Playing Lean Simulations Online), the facilitator explained the rules and instructions and randomly divided participants into two separate breakout rooms (i.e., control and experimental) using Zoom. Separate links to the game were sent to each group, and they were invited to play. Since learning to play the game effectively takes some practice, the researcher compared participants' performances between Levels (i.e. "rounds") 1 and 4. The difference between the average distances between Rounds 1 and 4 shows improved performance. The mean of the enhanced performance for the control group was -5.23 units. The negative value indicates that the travel distance was shortened (i.e., improved by 8.4%) in the latter round.

The experimental group played a version of the online game in which the spaghetti diagram was depicted at the end of play. The distance travelled and selected layout for each round was collected. According to Table 2, the difference of the average distances between rounds 1 and 4 shows improved performance. The mean of the enhanced travel distance performance for Group B (experimental) is -10.86 units. The negative mean suggests the cook's path in round 4 versus round 1 was shortened by 10.86 units (improved by 51.84%), which is greater than that found for Group A (control). A comparison of the averages of the improved performances between the two groups suggests that the participants who played the version with a spaghetti diagram showed greater improvement in terms of travel distance. Data collected from Group A (control) and Group B (experimental) are summarized in Table 2. The control group played a version of the online game in which participants were given access to their travel distances after each round; however, a spaghetti diagram was not made available to them.

Although the improvement in travel distance for participants using the spaghetti diagram was not statistically significant, data analysis revealed that the experimental group was more successful in identifying an optimized layout for the kitchen. Specifically, 70% of the experimental group participants chose layout C, compared to only 30% of the control group participants. This suggests that the spaghetti diagram was effective in helping participants understand that layout C, which involves placing the sink and stovetop closer together, would reduce wasted transportation and motion (as measured by travel distance).

Results of the paired t-test results are as follows:

- The two-tailed P value equals 0.1261. This difference is not considered statistically significant. Therefore, the null hypothesis cannot be rejected and a spaghetti diagram of the cook's path did not help the participants improve their performance;
- The mean of the Control Group minus the Experimental Group equals 5.63; and
- A 95% confidence interval of this difference is from -1.633 to 12.96.

To further illustrate this point, Figures 4 and 5 depict examples of spaghetti diagrams that experimental group participants saw after playing each round. The spaghetti diagram in Figure 4 shows a total travel distance of 53.07 units for layout A, where the stove is located further from the sink. In contrast, the spaghetti diagram in Figure 5 shows a total travel distance of 42.89 units for layout C, where the stove is located close to the sink.

Interestingly, data analysis showed that layout C was the only layout where participants could minimize their travel movements. Moreover, the best performance among participants came from a participant in the experimental group. To determine the significance of this result, a Chi-Square test was performed, resulting in a chi-square statistic of 9.6 and a p-value of 0.001946. This indicates that there was a significant difference between the experimental and control groups in terms of choosing layout C, as shown in Table 3.

Figure 1: Spaghetti Kitchen Online Game (Control Version)

Figure 2: Spaghetti Kitchen Online Game (Experimental Version)

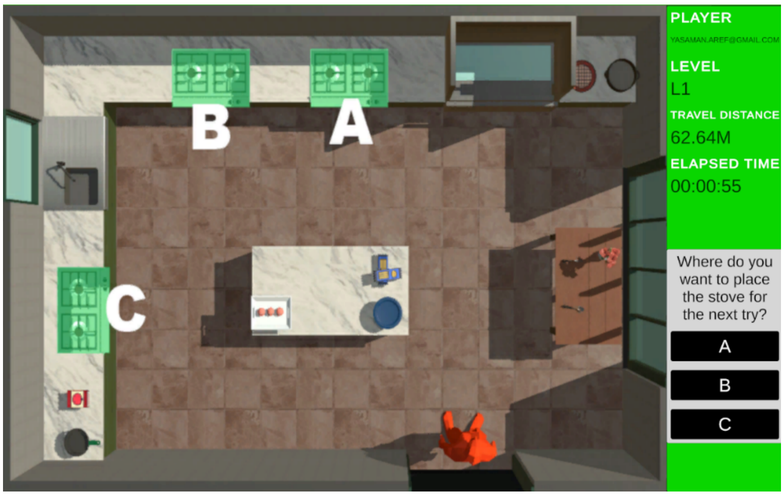

Figure 3: Stovetop Layout Options Given on Both Experimental and Control Versions.

Table 1: Online Game Participants and Dates

1	**Students**	37 graduate students taking COSC663 (Sustainable Construction) at Texas A&M University.	09/22/2022
		15 masters and PhD students from the Department of Construction Science at Texas A&M University	09/28/2022
2	**Lean experts**	8 Lean Experts from APLSO*	10/03/2022
		*Administering and Playing Lean Simulations Online (APLSO) is a voluntary, international online lean construction group that tests and gives feedback on novel online lean simulations.	

Table 2: Comparison of mean travel distances between control and experimental groups

	Group A (Control)	**Group B (Experimental)**
N	30	30
Mean	-5.2253	-10.8617
Standard Deviation	12.0122	15.8546
Standard Error of the Mean	2.1931	2.8946

The experimental group participants were asked to provide feedback on how they used the spaghetti diagram to identify strategies to improve their performance. The responses provided valuable insights into the benefits of using the spaghetti diagram, including:

- Identifying and focusing on long travel distances;
- Visualizing their movements through the spaghetti diagram;
- Recognizing the importance of having utensils, stove, and sink located closer to each other to reduce unnecessary time and space requirements;
- Optimizing the layout by placing the stove closer to the sink;
- Organizing the retrieval of items in a logical order based on distance traveled;

- Gaining a better understanding of their displacement and movements through the geometry of the spaghetti diagram and the repetitive lines, which showed where more attention was needed;
- Designing a better path to improve their workflow; and
- Identifying and eliminating wasteful movement.

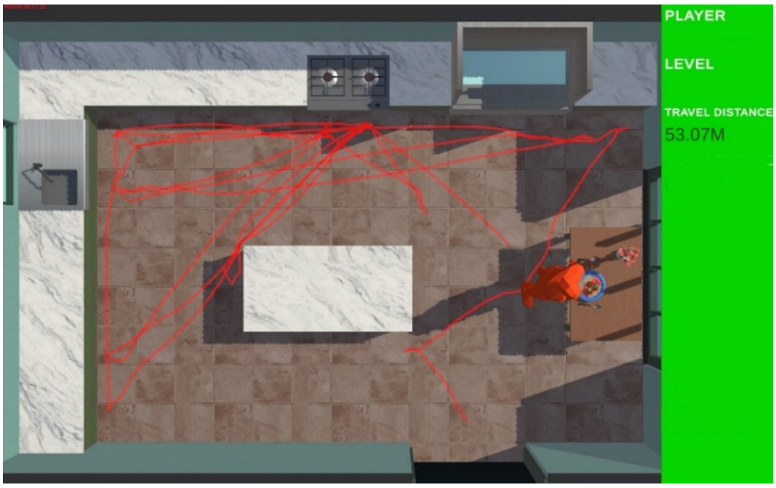

Figure 4: Example of spaghetti diagram in layout A

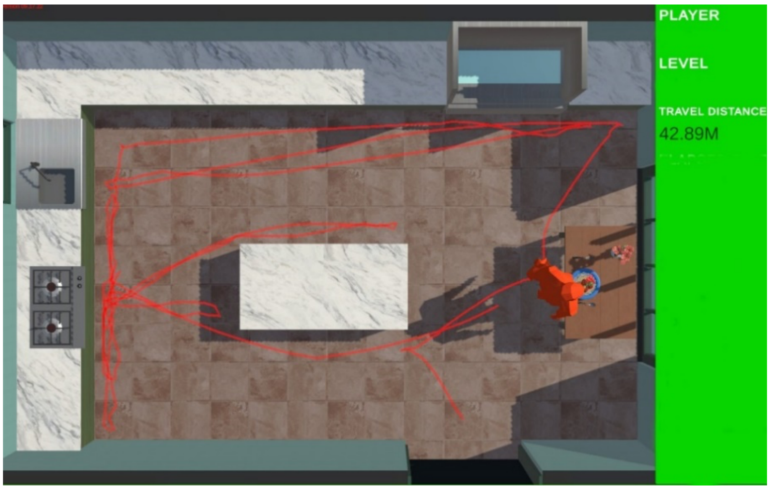

Figure 5: Example of spaghetti diagram in layout C.

Finally, feedback from participants of the online game was collected and examples of feedback included: *Plus*: Engaging graphics, fun to play, intuitive, useful; *Delta*: Add more options for rearrangement of appliances and create next stage of this game for construction.

Table 3: Number of times layout C was chosen by participants.

Type	Layout C	Other Layouts	Row total
Experimental Group	21	9	30
Control Group	9	21	30
Totals	**30**	**30**	**60**

These findings underscore the potential benefits of using spaghetti diagrams in optimizing workflow and reducing waste in a variety of contexts. Although further research is certainly needed to fully explore their impact, the study provides potential insights into their effectiveness in the context of layout optimization.

DISCUSSION

There are certainly limitations to this research. For example, different participant groups were combined due to time and resource limitations, and the sample sizes were relatively small. The researchers did not ask participant to share their background so there is no knowledge about which players may have more experience with Lean and waste identification than others. Another limitation of the research itself is that the game was primarily tested on university-level graduate students who plan to enter the construction industry. As such, the research represents a first-run study. Further research with on-site construction workers and project managers is needed to validate the simulation's effectiveness within the construction industry.

There are limitations with the currently designed game as well. For example, the designed online game cannot be played until the rules and instructions are explained to players. Instructions can certainly be shared through a pre-recorded video, for example, but there are benefits to having a live facilitator assist participants who may need additional guidance regarding moving and interacting with the objects. Playing should be followed up with discussions about potential applications to actual construction scenarios as the intent of using a commonly shared activity such as making spaghetti is to introduce participants to a fundamental lean concept that then can be applied to a task to which many participants can relate. For example, by using a software program, steel girders can digitally replace packages of spaghetti and cranes can easily be swapped with stove tops.

The ultimate goal of this work is to help users heighten their awareness of ways to improve workflows using the online game as a preliminary training tool to expose participants to their own movements. The intent is to help them self-identify wasted movement and therefore opportunities for productivity improvement when performing their own work. Because they are automated and internet-accessible, both the video and online simulation game offer the possibility of expanded geographic reach to potentially exceed what physical, in-seat simulations can do. This can offer a substantial benefit to multinational companies seeking to simultaneously train personnel in different parts of the globe.

CONCLUSION

Results from this research suggest that spaghetti diagrams, and other alternative ways to map construction processes, may be effective in increasing awareness of waste reduction and improving performance among those trained in the construction industry. There are opportunities for future research, including investigations into the applications of this simulation to actual construction scenarios. This could involve tracking and recording movements of workers or equipment and projecting them onto the ground in the shape of a spaghetti diagram for visual observation.

By adapting the online simulation game to depict construction activities on an actual project, with locations for material delivery, logistics, and laydown areas, there is potential to further enhance the game's effectiveness. Additionally, designing and testing the game in a three-dimensional (perspectival) view instead of a two dimensional (plan) view could provide valuable insights into its intuitiveness and effectiveness for those practicing in the construction industry. Overall, these findings offer exciting possibilities for future research and innovation in this field.

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